WBS 6.6: Muons Management Overview

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Level-2 Manager
University of Michigan

Conceptual Design Review for the High Luminosity LHC Detector Upgrade
National Science Foundation
Arlington, Virginia
March 8-10, 2016

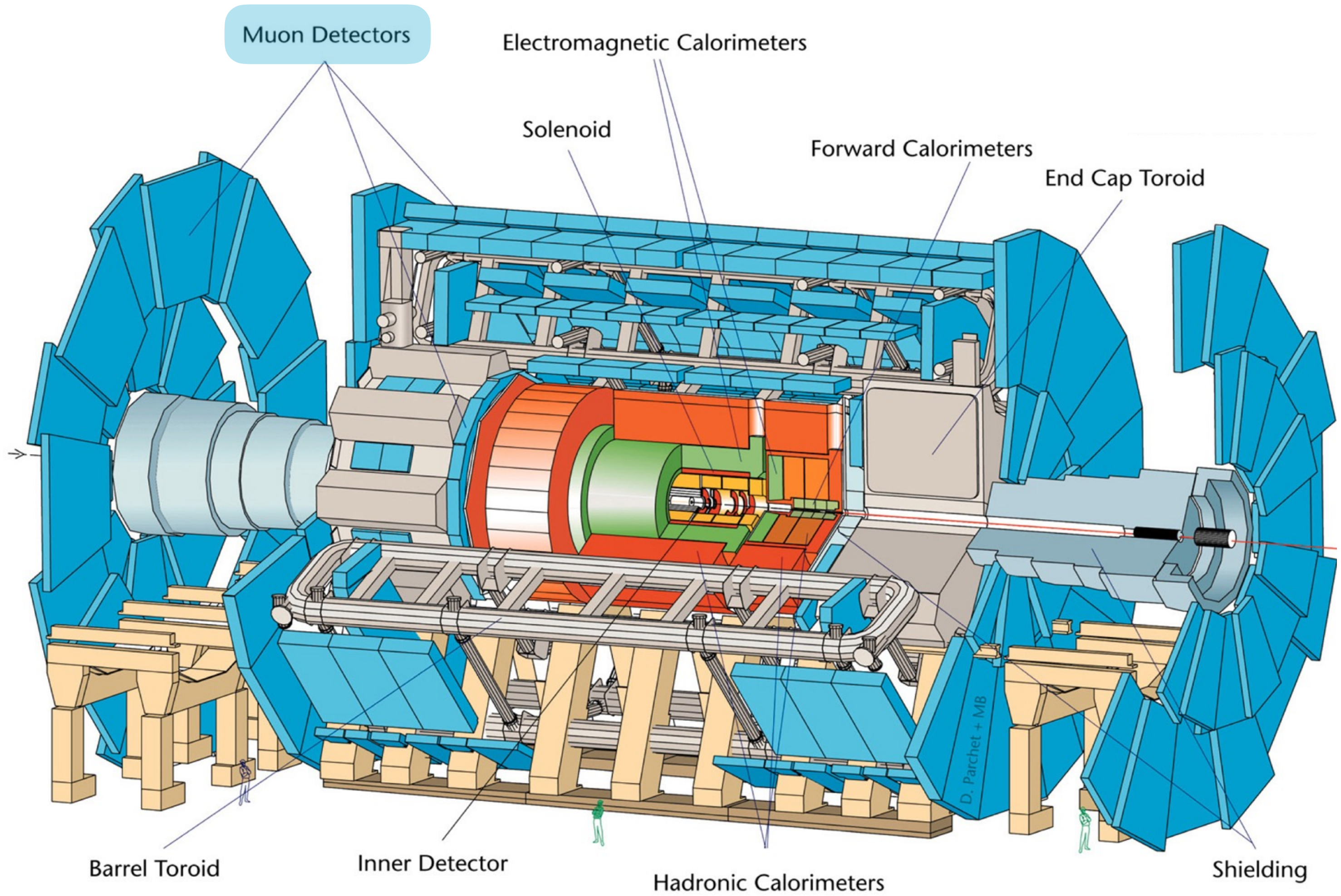
Level-2 Manager Bio

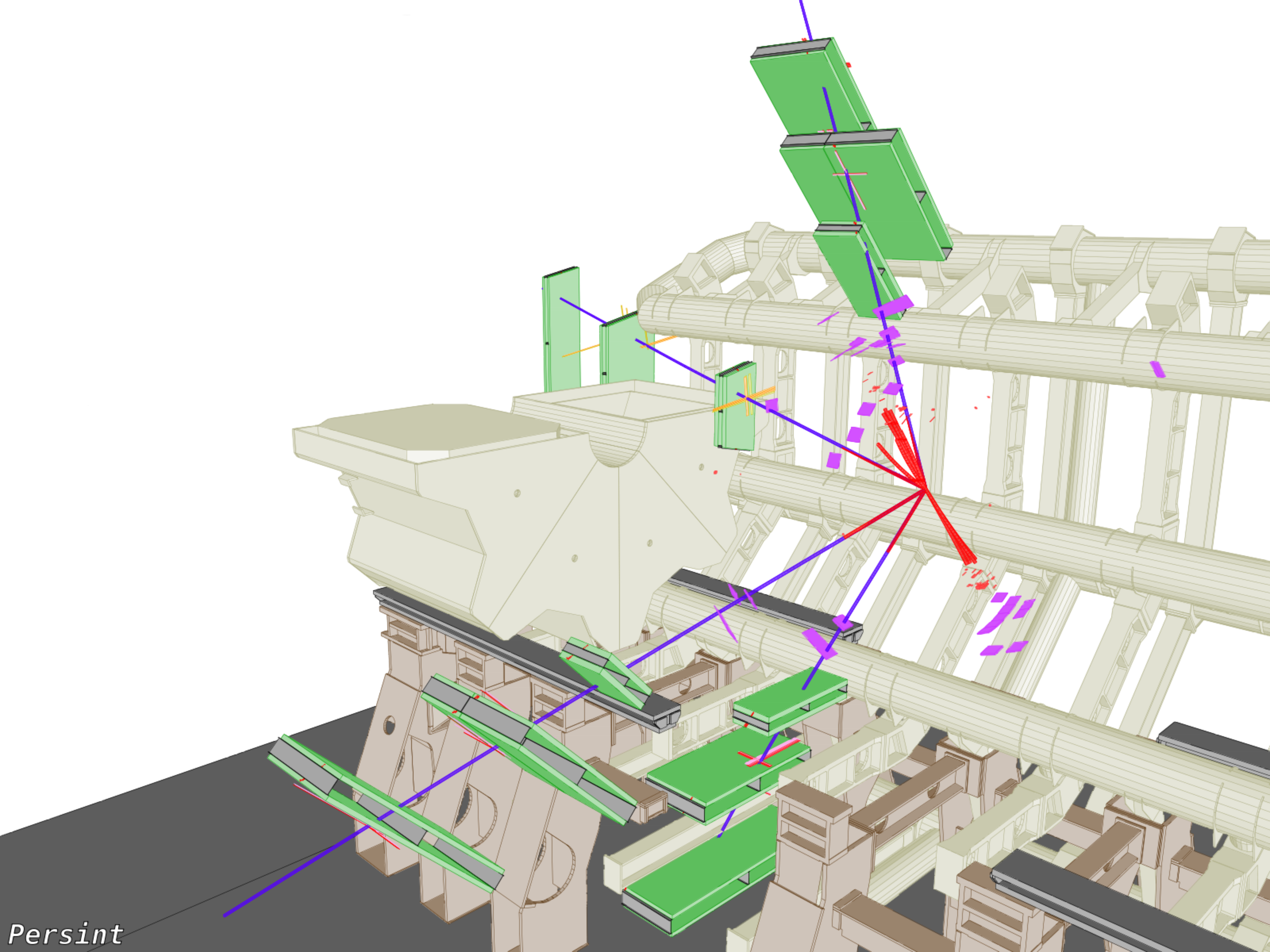
- Tom Schwarz
  - Assistant Professor at the University of Michigan
  - Previous experiments: CDF and CMS (over a decade of experience in HEP)
  - Current Level 2 Construction Manager for the HL-LHC Upgrade of the Muon Spectrometer
  - Leads the R&D effort for the HL-LHC Upgrade at the University of Michigan
  - Project Lead for the sTGC trigger signal packet router for the Phase I upgrade of the ATLAS new small wheel
  - co-editor of the MDT electronics section for the HL-LHC IDR
  - Invited reviewer for the muon spectrometer section of the HL-LHC upgrade scoping document
  - BSE and MSE in Electrical Engineering
  - 3 years of experience with silicon micro-machining, RF engineering, and microwave circuitry design

Outline

- Muon Spectrometer Overview
- Physics and Technical Requirements
- Proposed US HL-LHC Upgrade Scope
- NSF Deliverables
- System Management and Integration
- Costing Breakdown
- Schedule and Risks
- Contingency
- Closing Remarks

ATLAS Muon Spectrometer

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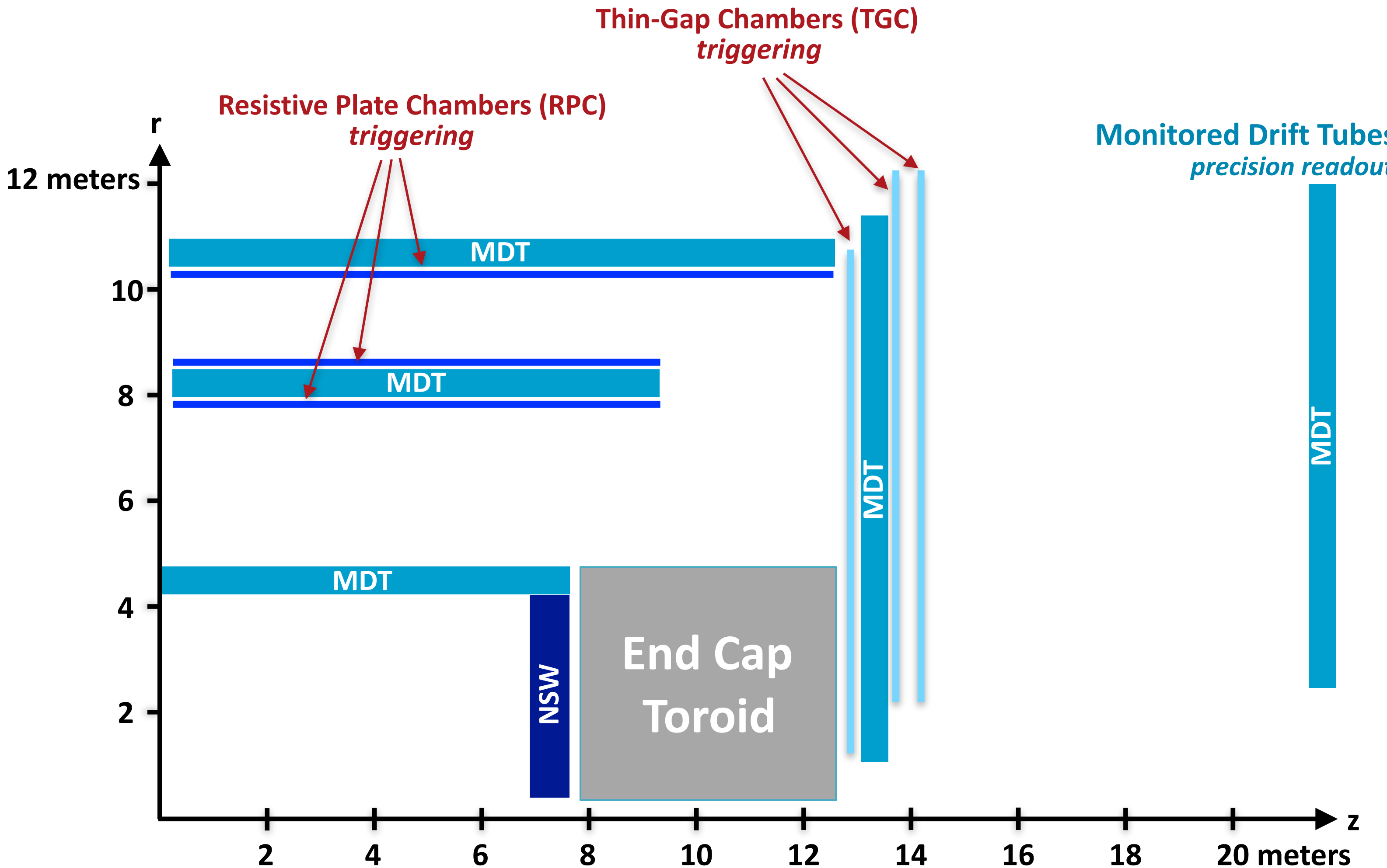
Muon Spectrometer (r-z view)



ATLAS Muon Upgrade Scope

Upgrades to the muon spectrometer (readout electronics and chambers) are required to handle increased rates and fakes associated with HL-LHC luminosities

To cope with high rates,

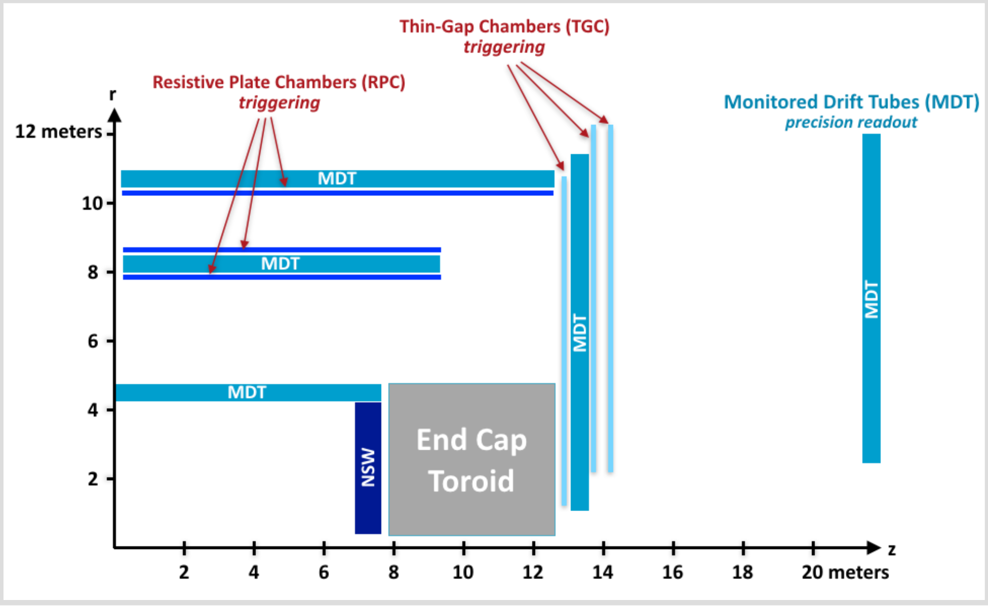
➡ The readout electronics of the MDT system must be replaced, as well as the barrel (RPC) and end-cap (TGC) triggering system.

To reduce fakes & improve trigger efficiency

➡ p_T selectivity of tracks for the trigger will be improved by integrating MDT information into triggering (Level-0).

➡ To reduce fakes at high η (2 < |η| < 2.4), new sTGC's will be installed in the inner ring of the big wheel.

➡ RPC and sMDT chambers will replace current MDT chambers in the inner barrel to allow for a 3-station MDT trigger



NSF Scope

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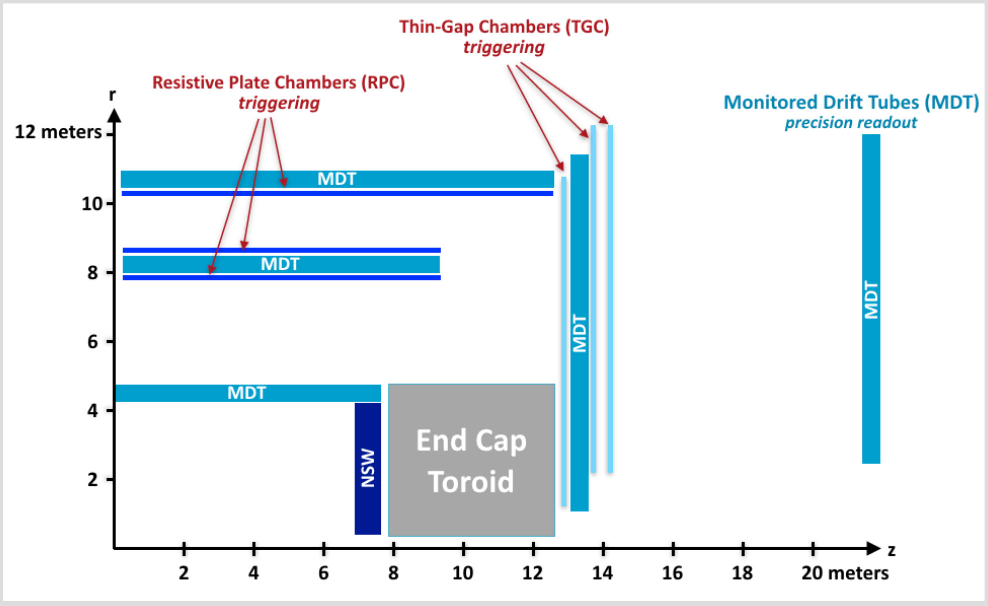

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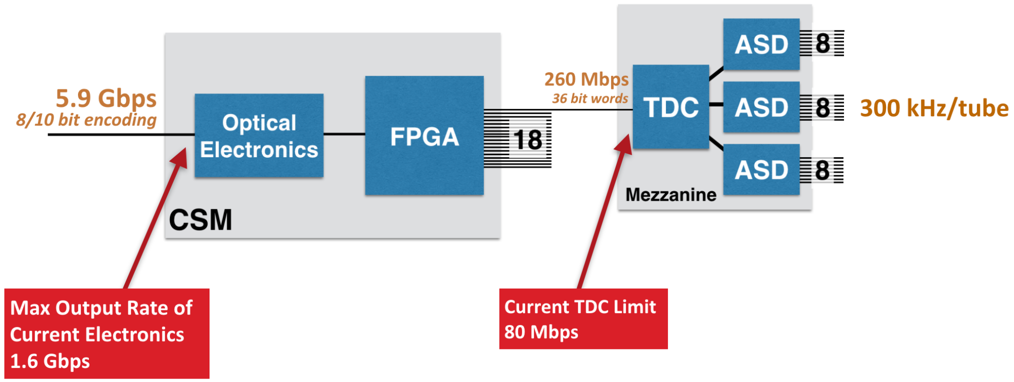

Readout electronics must be able to handle 300 kHz/tube hit rate and a 1 MHz trigger, which is not possible in the current system.

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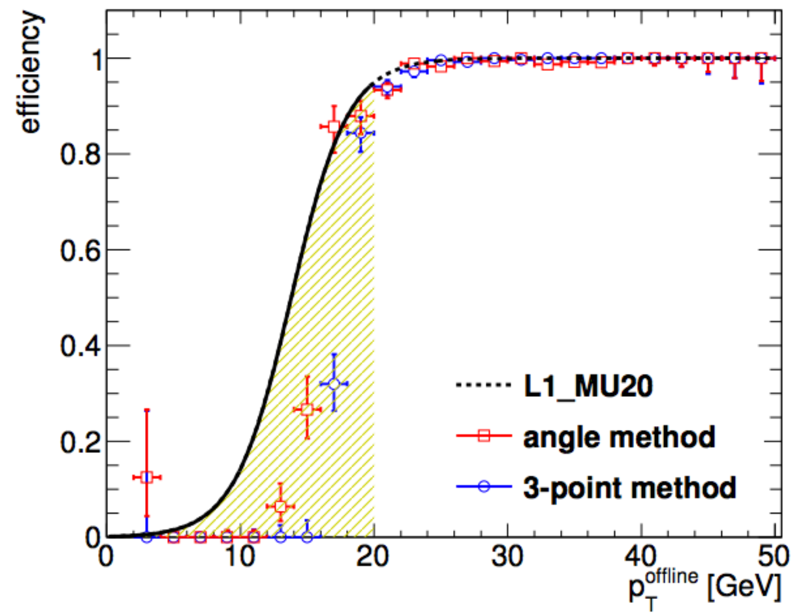

MDT muon trigger turn-on curves for a two-station (red) and three station (blue) trigger compared with the RPC L0 muon turn-on curve (black) in simulated data. Sharpening the turn-on curve will reduce the muon fake rate by 4x.

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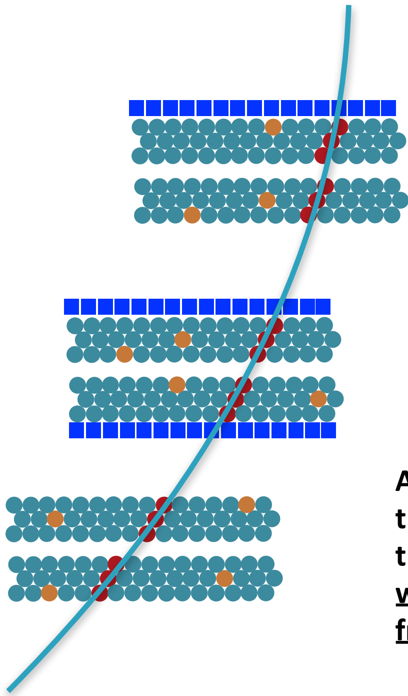

Adding RPC/MDT detectors to the inner barrel will allow for three-station triggering. <u>This will improve trigger efficiency from 65 to 95% at the HL-LHC.</u>

HL-LHC Science Goals

SCIENCE GOALS	SCIENCE REQUIREMENTS	NSF SCOPE
$H \rightarrow 4\mu$ (2.2%) VBF $H \rightarrow ZZ^*$, WW^* (17%,14%) VBS ssWW (5.9%) SUSY $\chi_1^\pm \chi_2^0 \rightarrow \ell bb+X$ (850 GeV)	Muon Trigger • single μ p_T threshold ~ 20 GeV • geometric accept: 95% (barrel)	• Muon Electronics • Tile Electronics • sMDT • L0Muon
VBF $H \rightarrow ZZ^*$, WW^* (17%,14%) VBS ssWW (5.9%) SUSY $\chi_1^\pm \chi_2^0 \rightarrow \ell bb+X$ (850 GeV)	Electron Trigger • single e p_T threshold ~ 22 GeV	• LAr+Tile Electronics • L1Global • L1Track/FTK++
$HH \rightarrow 4b$ (4.4σ KK Graviton)	Jet Triggers • 4-jet E_T threshold ~ 75 GeV • “fat” jet threshold ~ 375 GeV • jet-vertex confirmation at L1	• Lar+Tile Electronics • L1Global • L1Track/FTK++
Compressed SUSY ($\chi_1^\pm \chi_2^0$)	Missing E_T Trigger • ME_T threshold ~ 200 GeV • track-based ME_T correction	• Lar+Tile Electronics • L1Global • L1Track/FTK++

Cost-Effective Trigger System that meets Science Requirements:
- <L0 accept>=1 MHz (6/10μs); <L1 accept>=400 kHz (30/60μs); <to storage>=10 kHz

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Triggering and recording High-p_T leptons (muons) are critical to nearly every physics objective of the ATLAS experiment.

Example: Higgs → 4μ

SCIENCE GOALS

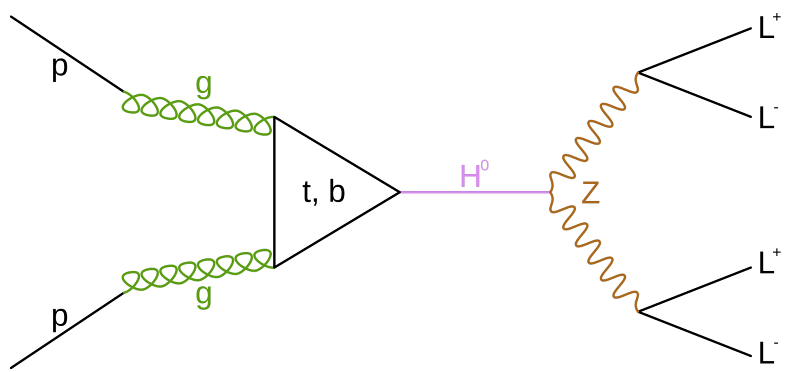
$H \rightarrow 4\mu$ (2.2%)
VBF $H \rightarrow ZZ^*, WW^*$ (17%,14%)
VBS ssWW (5.9%)
SUSY $\chi_1^{\pm}\,\chi_2^{0} \rightarrow \ell bb+X$ (850 GeV)

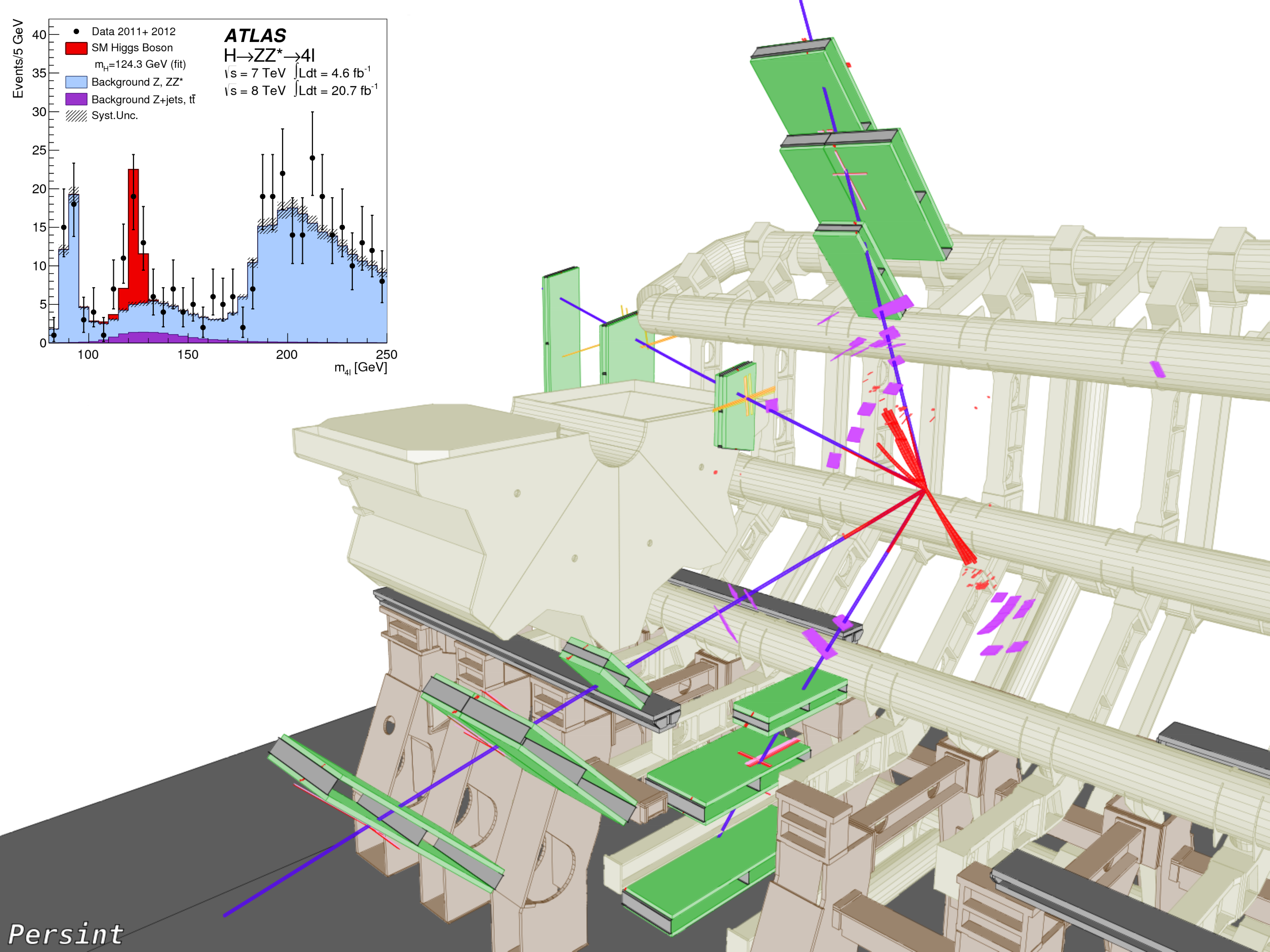
SCIENCE REQUIREMENTS

Muon Trigger
- single μ p_T threshold ~ 20 GeV
- geometric accept: 95% (barrel)

NSF SCOPE

- Muon Electronics
- Tile Electronics
- sMDT
- L0Muon





Events/5 GeV
Data 2011+ 2012
SM Higgs Boson
m_H=124.3 GeV (fit)
Background Z, ZZ*
Background Z+jets, tt̄
Syst.Unc.
ATLAS
H→ZZ*→4l
√s = 7 TeV ∫Ldt = 4.6 fb-1
√s = 8 TeV ∫Ldt = 20.7 fb-1
m_4l [GeV]
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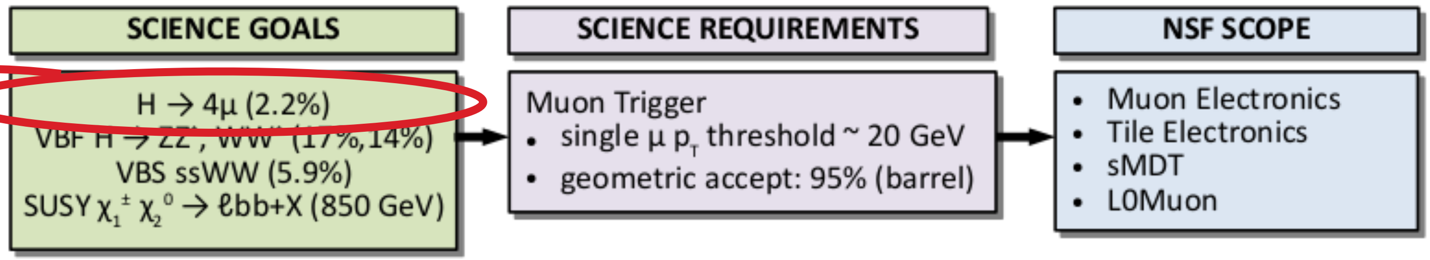
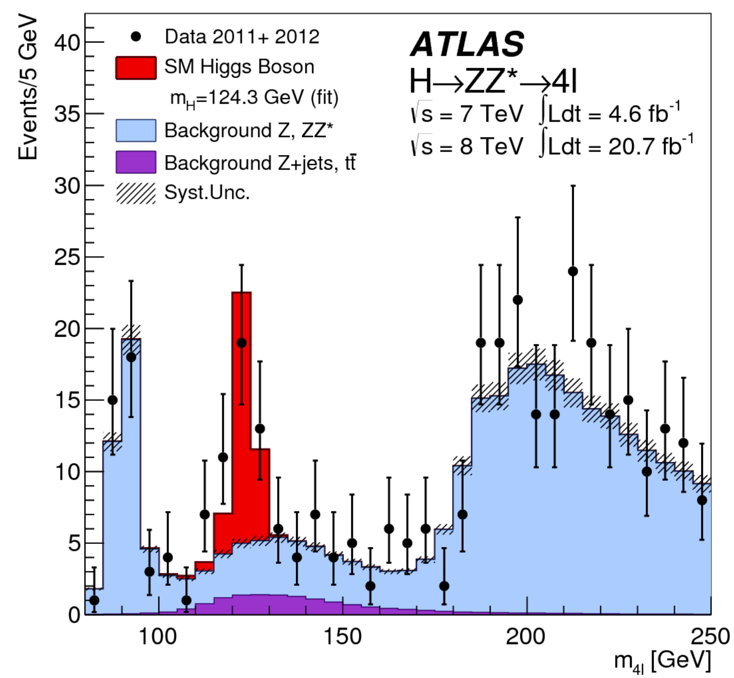
Example: Higgs → 4μ



- **Many new physics models result in <u>small</u> differences in the rate of Higgs boson production with respect to the standard model (Higgs Composite Models). This necessitates precision measurements of rates in all channels.**

- **2.2% represents maximizing the potential of the experiment for this measurement (statistical uncertainty = systematic uncertainty)**

- **The measurement precision of the h→4μ rate is driven by statistics (event acceptance)**



Example: Higgs → 4μ

SCIENCE GOALS

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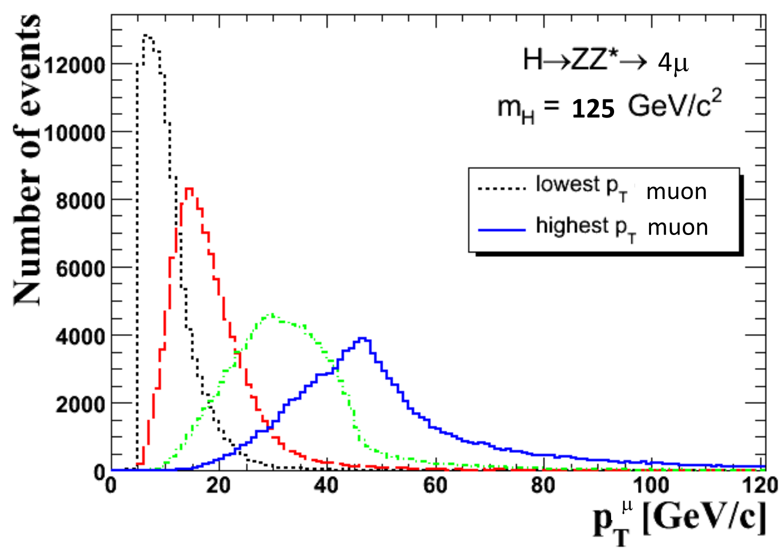
SCIENCE REQUIREMENTS

Muon Trigger
- single μ p_T threshold ~ 20 GeV
- geometric accept: 95% (barrel)

NSF SCOPE

- Muon Electronics
- Tile Electronics
- sMDT
- L0Muon

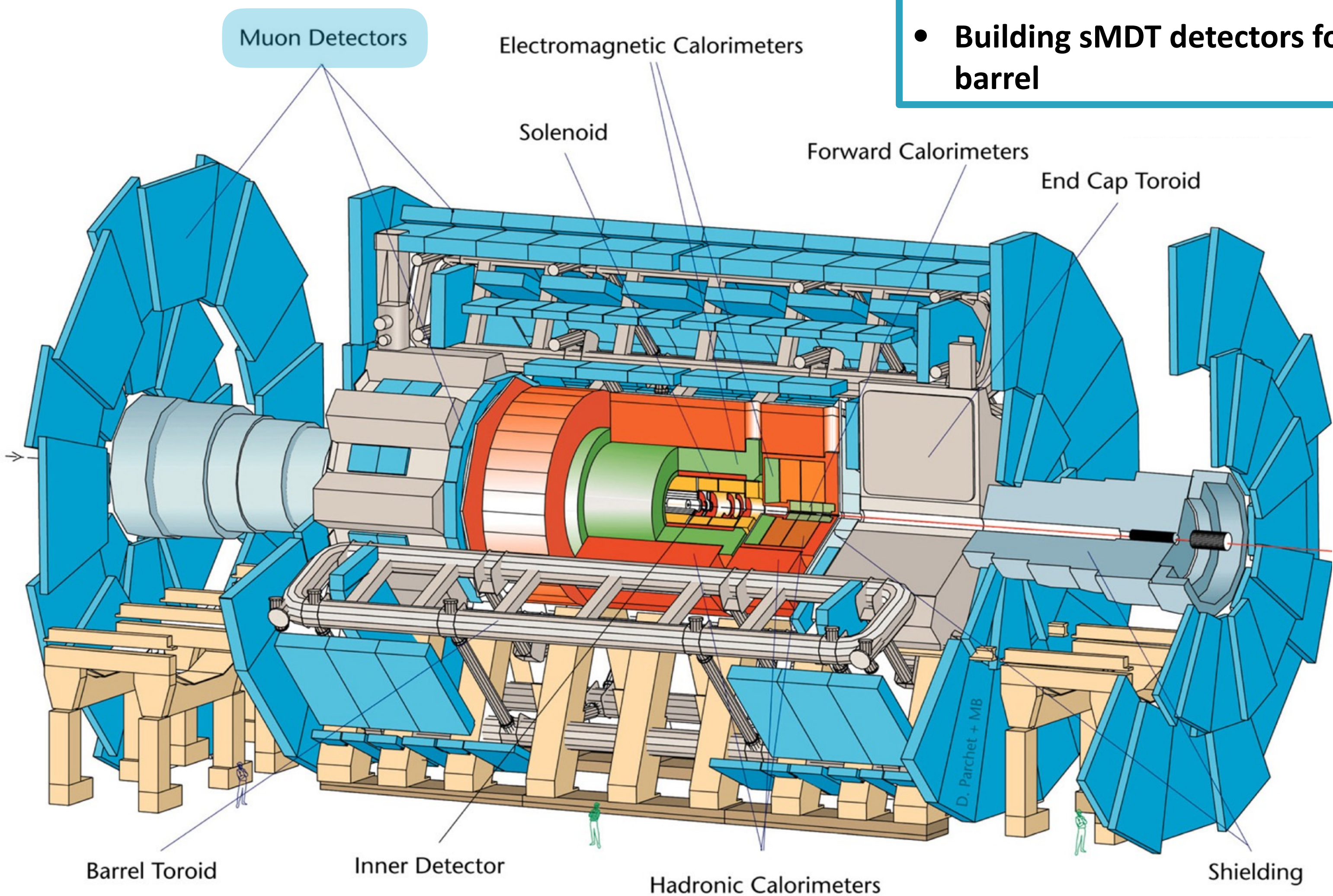
- Without the HL-LHC upgrade, we cannot handle the increased trigger rates, and therefore can't maintain the single muon p_T threshold of 20 GeV
- To handle the increased background rates we could raise the trigger threshold to 40 GeV.
- However, this would decrease the h➔4μ acceptance by factor of ~2.
- To reach maximum potential of the experiment, we would then need to run the experiment 2x longer (assuming hardware could withstand this lifetime)



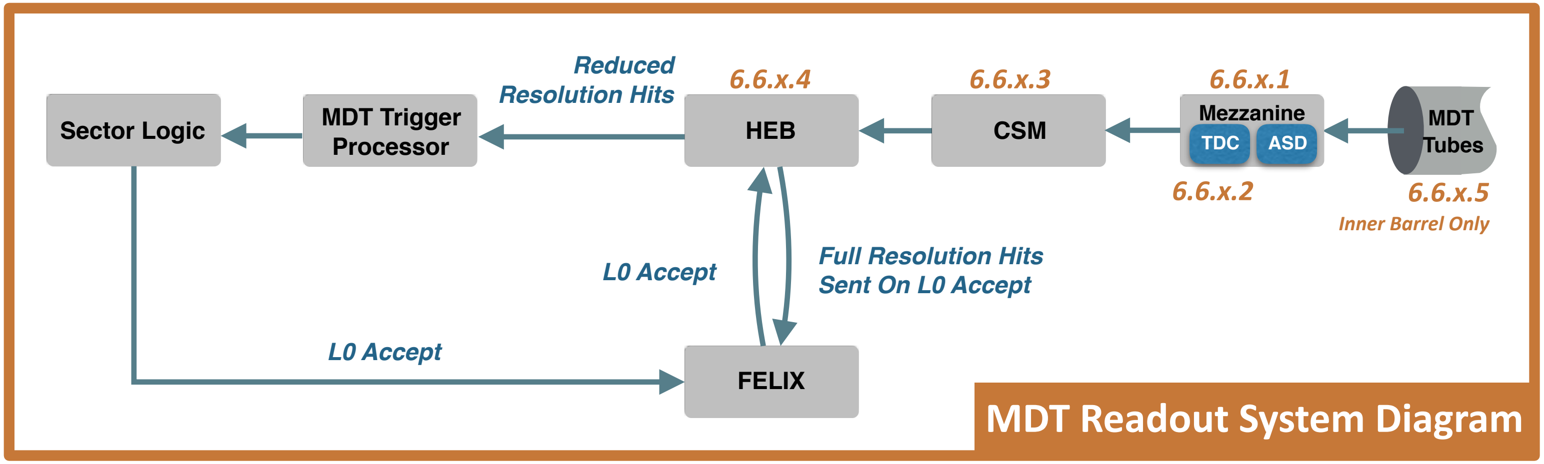
NSF Scope: MDT System

Improving Trigger Efficiency and Precision Tracking

- **Replacing readout electronics for the entire MDT system (blue)**
- **Building sMDT detectors for the inner barrel**

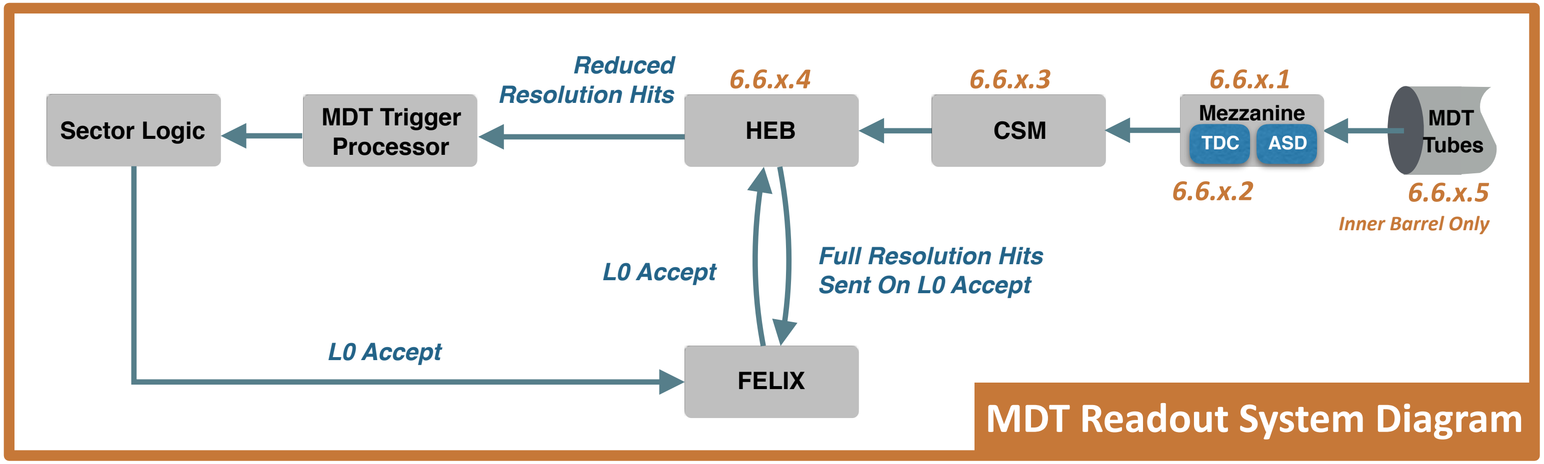


Summary of the NSF Scope



WBS	Deliverable	Functionality	# Produced by US	US Institutes	International Interests
6.6.x.1	**PCB for Mezzanine**	PCB board for the Mezzanine Card, which consists of three ASD and one TDC chips.	17,225 boards	University of Arizona ***6.6.1.1***	*none*
6.6.x.2	**Time-to-Digital Converter (TDC)**	Stores arrival times of the leading and trailing edges of the MDT signal (asic chip)	22,000 chips	University of Michigan ***6.6.3.2***	MPI (Collaborative), Japan
6.6.x.3	**Chamber Service Module (CSM)**	Data are formatted, stored, and sent via optical link to the Hit Extraction Board (HEB)	1300 boards	University of Michigan ***6.6.3.3***	*none*
6.6.x.4	**Hit Extraction Board (HEB)**	Sends reduced resolution hits to the trigger processor and on a Level 0 accept sends full resolution hits to FELIX for readout	24 boards	University of Illinois Urbana-Champaign ***6.6.4.4***	*none*
6.6.x.5	**sMDT**	Short monitored drift tubes to be paired with new RPC's on inner barrel for trigger	48 chambers	Michigan State University (tubes) ***6.6.5.5*** University of Michigan (chambers) ***6.6.3.5***	MPI and Protovino (Collaborative - 50%)

End of Project



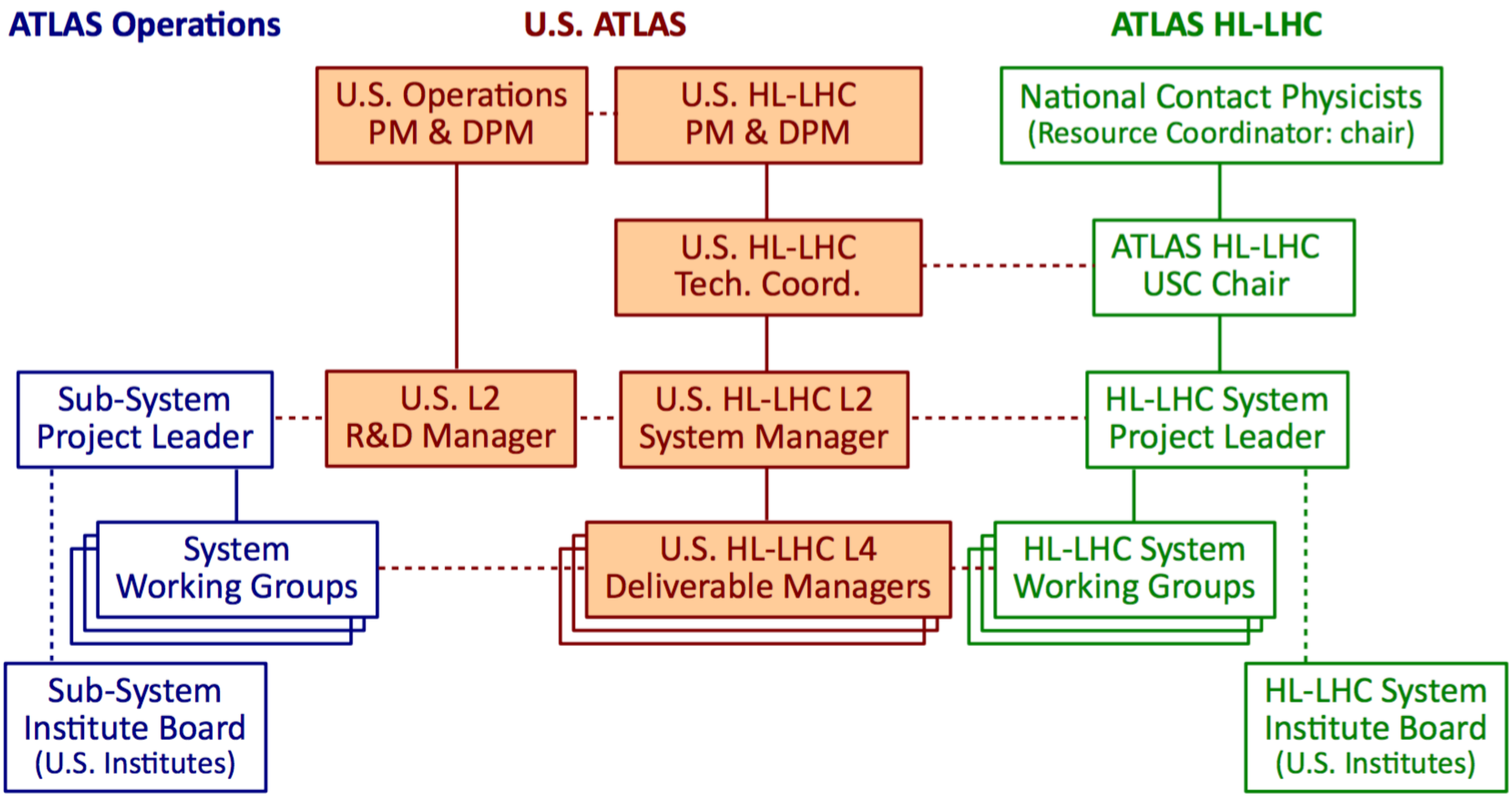
WBS	Deliverable	# Produced by US	US Institutes	End of Project
6.6.x.1	**PCB for Mezzanine**	17,225 boards	University of Arizona ***6.6.1.1***	Delivery of all PCB boards to CERN, fully assembled and tested
6.6.x.2	**Time-to-Digital Converter (TDC)**	22,000 chips	University of Michigan ***6.6.3.2***	Delivery of all chips to mezzanine assembly house, after testing
6.6.x.3	**Chamber Service Module (CSM)**	1300 boards	University of Michigan ***6.6.3.3***	Delivery of all boards to CERN after testing
6.6.x.4	**Hit Extraction Board (HEB)**	24 boards	University of Illinois Urbana-Champaign ***6.6.4.4***	Deliver of all boards to CERN after testing
6.6.x.5	**sMDT**	48 chambers	Michigan State University (tubes) ***6.6.5.5*** University of Michigan (chambers) ***6.6.3.5***	Delivery of 48 chambers to CERN, acceptance tested

NSF Fraction of the Muon Upgrade

NSF FRACTIONS OF HL-LHC MUON SPECTROMETER UPGRADE

ATLAS WBS	ATLAS Item (Scoping Doc)	US WBS	Deliverable	NSF Fraction Design	NSF Fraction Production
5	**Muon Spectrometer**	**6.5**	**Muon Spectrometer**		**20%**
5.1	**MDT**				
5.1.1	sMDT detector				
			sMDT Tubes	50%	50%
			sMDT Chambers	50%	50%
5.1.2	sMDT installation basket				-
5.1.3	Mezzanine cards				
			PCB Board	100%	100%
			ASD		-
			TDC	100%	100%
5.1.4	CSM cards				
			CSM	100%	100%
			Hit Extraction Board	100%	100%
5.2	**RPC**				
5.2.1	Detectors				
5.2.2	Installation mock-up				
5.2.3	Installation tooling				
5.2.4	On-detector electronics (DCT)				
5.3	**TGC**				
5.3.1	On-detector electronics PS)				
5.3.2	sTGC on BW inner ring				
5.4	**High Eta-Tagger**				
5.4.1	Detector				
5.4.2	FE electronics				
5.4.3	Services and infrastructure				
5.5	**Power System**				
5.5.1	MDT				
5.5.2	RPC				
5.5.3	TGC				

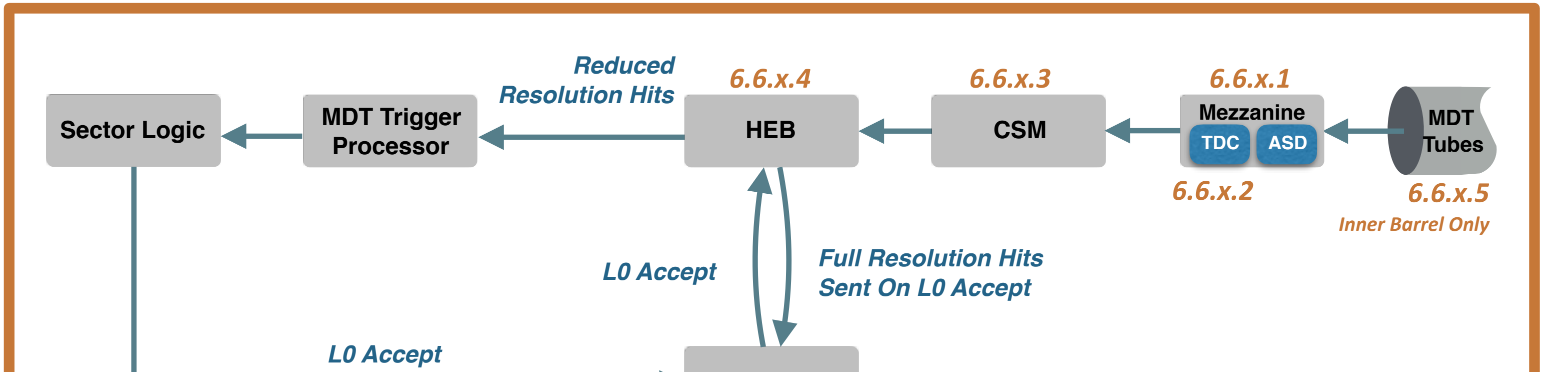
ATLAS Organization



External Dependencies

HL-LHC EXTERNAL DEPENDENCIES FOR NSF DELIVERABLES

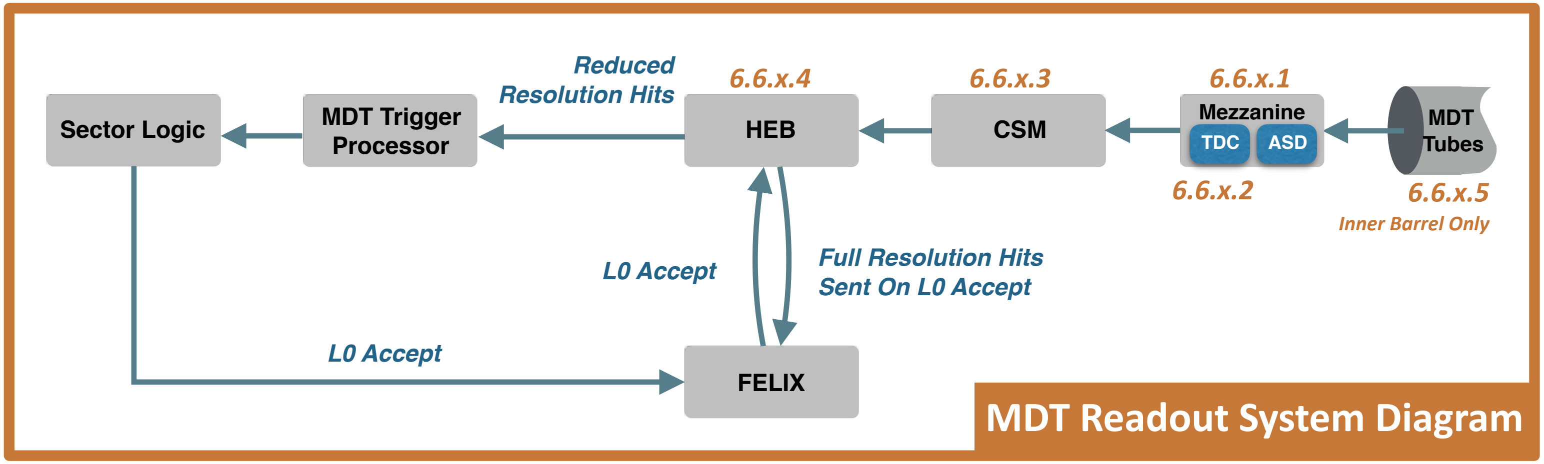
WBS	Title	Item	External Dependency	Mitigation Strategy
6.6	**Muon**			
6.6.x.1	Mezzanine Card		ASD (Germany)	Engineers at US institutes are closely collaborating with German institutues working on the ASD. Delays in the ASD will only affect pre-construction/construction. Based on the ASD timescale, several months of delay in final production of the ASD will not affect Mezzanine production. say 2 years of FLOAT
6.6.x.2	TDC		ASD (Germany)	Engineers at US institutes are closely collaborating with German institutues working on the ASD. Delays in the ASD will not affect the TDC development.
6.6.x.3	CSM		project is self-contained to NSF	
6.6.x.4	HEB		project is self-contained to NSF	
6.6.x.5	sMDT		project is self-contained to NSF	



MDT Readout System Diagram

System Management & Integration

- Dan Levin (Senior Research Scientist at the University of Michigan) has agreed to act as Integration Engineer for the US HL-LHC upgrade of the Muon System.
- Primary Responsibilities
  - Organize “Expert Weeks” during R&D and pre-production
  - Organize reviews of designs and ensure CERN requirements have been met.
  - Monitor project schedules, identify and address any problems.
  - Liaison with the international ATLAS muon project leaders

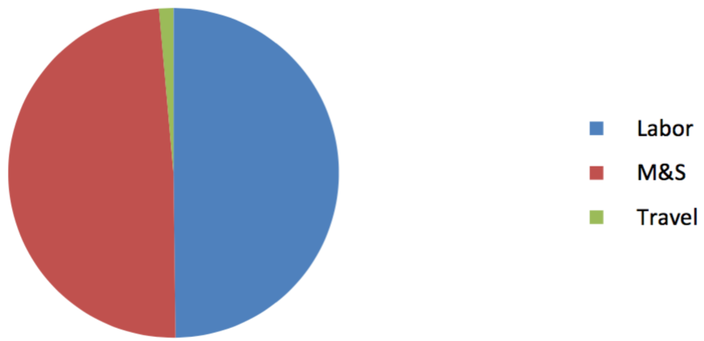


Budget and Effort

Estimates based on the following:

- **LABOR**: previous experience with similar deliverables and salaries of current employees capable of work - scaled by inflation
- **PRODUCTION M&S**: similar previous deliverable scaled by inflation, with quotes used for any known new components
- **PROTOTYPE M&S**: costs scaled from other similar developed prototypes, and quotes from fabrication houses
- **TRAVEL**: Known travel for specific needs, and some regular travel between collaborating institutions

WBS 6.6 Muon L2 NSF Resource Breakdown

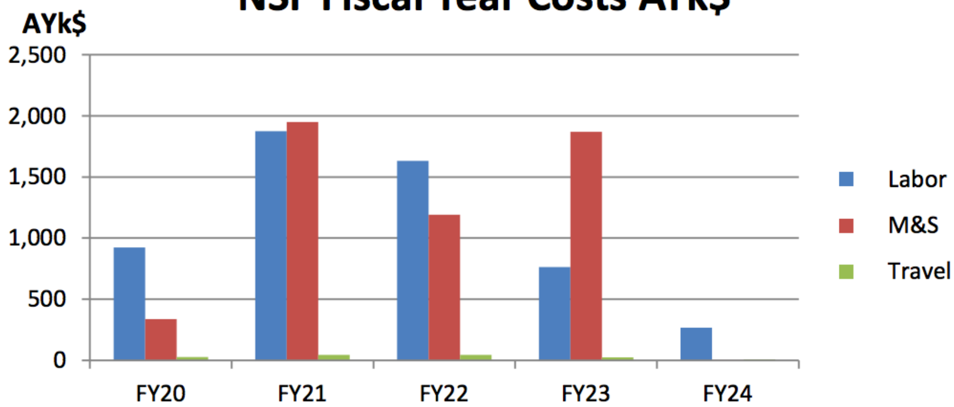


Costing of Individual Deliverables described in detail in BoE's

6.06 Muon NSF Total Cost (AYk$)						
	FY20	FY21	FY22	FY23	FY24	Grand Total
NSF						
Labor	923	1,874	1,632	764	267	5,460
M&S	339	1,949	1,192	1,868	2	5,350
Travel	28	45	45	27	8	154
NSF Total	**1,291**	**3,868**	**2,869**	**2,659**	**277**	**10,964**

Budget and Effort

- Profile is defined by deliverables needed for sMDT detectors, which are installed earlier. This includes the sMDT's, TDC, and CSM.
- Later required deliverables, the PCB for the MDT's and the HEB, are responsible for the FY23 jump in M&S.
- Engineer Labor is high in early years for design, technician labor ramps to later years for construction



6.6 Muon NSF Total Cost by deliverable (AYk$)

Deliverable/Item	FY20	FY21	FY22	FY23	FY24	Total
6.6.1.1 PCB for Mezzanine	138	261	302	1,253	92	2,046
6.6.3.2 TDC	163	387	919	124	-	1,593
6.6.3.3 CSM	224	1,688	364	156	-	2,432
6.6.3.4 HEB	174	347	348	1,126	185	2,180
6.6.x.5 sMDT	**591**	**1,185**	**936**	**-**	**-**	2,713
6.6.3.5 sMDT	321	648	497	-	-	1,466
6.6.5.5 sMDT	270	537	439	-	-	1,246
NSF Grand Total	**1,291**	**3,868**	**2,869**	**2,659**	**277**	**10,964**

Budget and Effort

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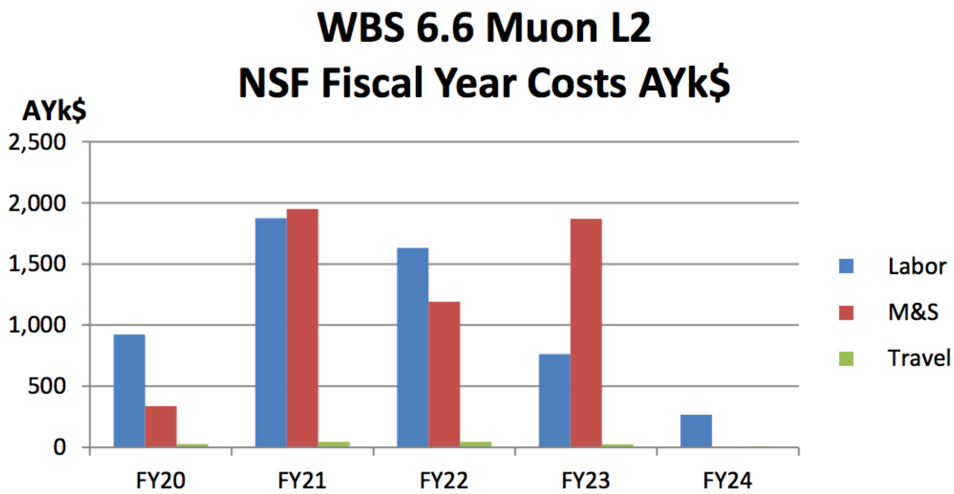
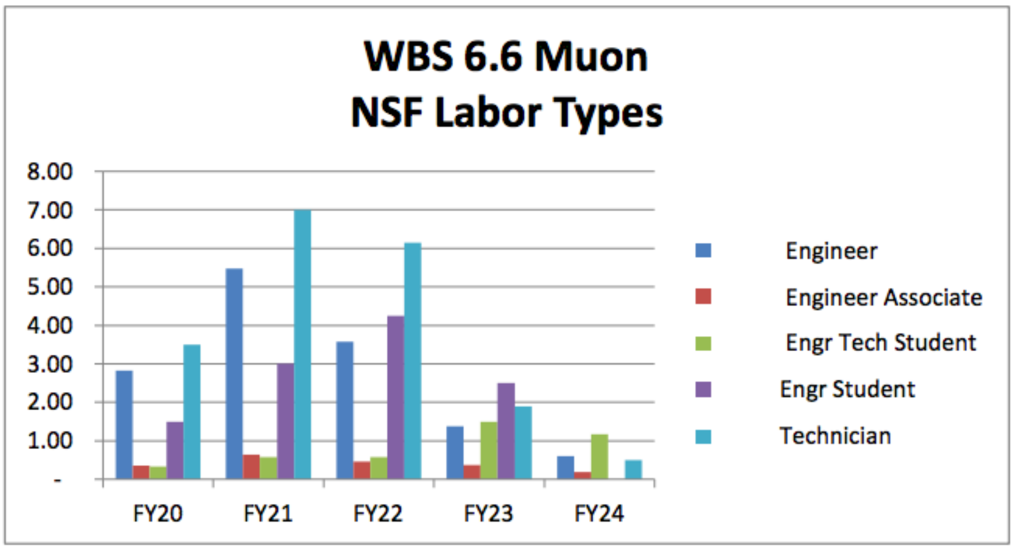
- Later required deliverables, the PCB for the MDT's and the HEB, are responsible for the FY23 jump in M&S.
- Labor ramps down after construction, modulated by the different deliverable end-dates.



6.6 Muon NSF Total FTEs by deliverable						
Deliverable/Item	**FY20**	**FY21**	**FY22**	**FY23**	**FY24**	**Grand Total**
6.6.1.1 PCB for Mezzanine	1.02	1.95	1.60	2.14	1.47	8.18
6.6.3.2 TDC	1.50	2.75	2.75	1.50	-	8.50
6.6.3.3 CSM	2.00	4.00	3.90	2.00	-	11.90
6.6.3.4 HEB	1.00	2.00	2.00	2.00	1.00	8.00
6.6.x.5 sMDT	**3.00**	**6.00**	**4.75**	-	-	13.75
6.6.3.5 sMDT	2.00	4.00	3.00	-	-	9.00
6.6.5.5 sMDT	1.00	2.00	1.75	-	-	4.75
NSF Grand Total	**8.52**	**16.70**	**15.00**	**7.64**	**2.47**	**50.33**

Labor Breakdown

- Engineer Labor is high in early years for design, technician and student labor ramps to later years for construction and QA/QC



6.6 Muon NSF Total FTEs by Labor Type						
Deliverable/Item	**FY20**	**FY21**	**FY22**	**FY23**	**FY24**	**Grand Total**
6.6.1 Muon_Arizona	**1.02**	**1.95**	**1.60**	**2.14**	**1.47**	**8.18**
6.6.1.1 PCB for Mezzanine	**1.02**	**1.95**	**1.60**	**2.14**	**1.47**	**8.18**
Engineer	0.32	0.72	0.57	0.28	0.11	2.00
Engineer Associate	0.36	0.64	0.46	0.37	0.19	2.02
Engr Tech Student	0.33	0.58	0.58	1.50	1.17	4.17
Engr Student	-	-	-	-	-	-
Technician	-	-	-	-	-	-
6.6.3 Muon_Michigan	**5.50**	**10.75**	**9.65**	**3.50**	**-**	**29.40**
6.6.3.2 TDC	**1.50**	**2.75**	**2.75**	**1.50**	**-**	**8.50**
Engineer	0.50	0.75	0.35	0.10	-	1.70
Engineer Associate	-	-	-	-	-	-
Engr Tech Student	-	-	-	-	-	-
Engr Student	0.50	1.00	1.50	1.00	-	4.00
Technician	0.50	1.00	0.90	0.40	-	2.80
6.6.3.3 CSM	**2.00**	**4.00**	**3.90**	**2.00**	**-**	**11.90**
Engineer	1.00	2.00	0.90	-	-	3.90
Engineer Associate	-	-	-	-	-	-
Engr Tech Student	-	-	-	-	-	-
Engr Student	0.50	1.00	2.00	1.50	-	5.00
Technician	0.50	1.00	1.00	0.50	-	3.00
6.6.3.5 sMDT	**2.00**	**4.00**	**3.00**	**-**	**-**	**9.00**
Engineer	0.50	1.00	0.75	-	-	2.25
Engineer Associate	-	-	-	-	-	-
Engr Tech Student	-	-	-	-	-	-
Engr Student	0.50	1.00	0.75	-	-	2.25
Technician	1.00	2.00	1.50	-	-	4.50
6.6.4 Muon_Illinois	**1.00**	**2.00**	**2.00**	**2.00**	**1.00**	**8.00**
6.6.4.4 HEB	**1.00**	**2.00**	**2.00**	**2.00**	**1.00**	**8.00**
Engineer	0.50	1.00	1.00	1.00	0.50	4.00
Engineer Associate	-	-	-	-	-	-
Engr Tech Student	-	-	-	-	-	-
Engr Student	-	-	-	-	-	-
Technician	0.50	1.00	1.00	1.00	0.50	4.00
6.6.5 Muon_MSU	**1.00**	**2.00**	**1.75**	**-**	**-**	**4.75**
6.6.5.5 sMDT	**1.00**	**2.00**	**1.75**	**-**	**-**	**4.75**
Engineer	-	-	-	-	-	-
Engineer Associate	-	-	-	-	-	-
Engr Tech Student	-	-	-	-	-	-
Engr Student	-	-	-	-	-	-
Technician	1.00	2.00	1.75	-	-	4.75
NSF Grand Total	**8.52**	**16.70**	**15.00**	**7.64**	**2.47**	**50.33**
Engineer	2.82	5.47	3.57	1.38	0.61	13.85
Engineer Associate	0.36	0.64	0.46	0.37	0.19	2.02
Engr Tech Student	0.33	0.58	0.58	1.50	1.17	4.17
Engr Student	1.50	3.00	4.25	2.50	-	11.25
Technician	3.50	7.00	6.15	1.90	0.50	19.05

Costs by Phase

6.6 Muon NSF Total Cost by Phase (AYk$)						
Deliverable/Item/Phase	**FY20**	**FY21**	**FY22**	**FY23**	**FY24**	**Grand Total**
6.6.1 Muon_Arizona	**138**	**261**	**302**	**1,253**	**92**	**2,046**
6.6.1.1 PCB for Mezzanine	**138**	**261**	**302**	**1,253**	**92**	**2,046**
Design	138	261	110	0	0	509
Prototype	0	0	191	65	0	256
Production	0	0	0	1,189	92	1,281
6.6.3 Muon_Michigan	**708**	**2,724**	**1,780**	**280**	**0**	**5,491**
6.6.3.2 TDC	**163**	**387**	**919**	**124**	**0**	**1,593**
Design/Prototype	163	153	0	0	0	316
Pre-Production	0	235	120	0	0	355
Production	0	0	798	124	0	922
6.6.3.3 CSM	**224**	**1,688**	**364**	**156**	**0**	**2,432**
Design/Prototype	105	6	0	0	0	111
Pre-Production	119	435	3	0	0	556
Production	0	1,247	362	156	0	1,765
6.6.3.5 sMDT	**321**	**648**	**497**	**0**	**0**	**1,466**
Tooling Construction	0	0	0	0	0	0
Tube Construction	0	0	0	0	0	0
Chamber Construction	321	648	497	0	0	1,466
6.6.4 Muon_Illinois	**174**	**347**	**348**	**1,126**	**185**	**2,180**
6.6.4.4 HEB	**174**	**347**	**348**	**1,126**	**185**	**2,180**
Design/Prototype	174	168	0	0	0	342
Pre-Production	0	178	173	0	0	352
Production	0	0	175	1,126	185	1,486
6.6.5 Muon_MSU	**270**	**537**	**439**	**0**	**0**	**1,246**
6.6.5.5 sMDT	**270**	**537**	**439**	**0**	**0**	**1,246**
Tooling Construction	0	0	0	0	0	0
Tube Construction	270	537	439	0	0	1,246
Chamber Construction	0	0	0	0	0	0
NSF Grand Total	**1,291**	**3,868**	**2,869**	**2,659**	**277**	**10,964**

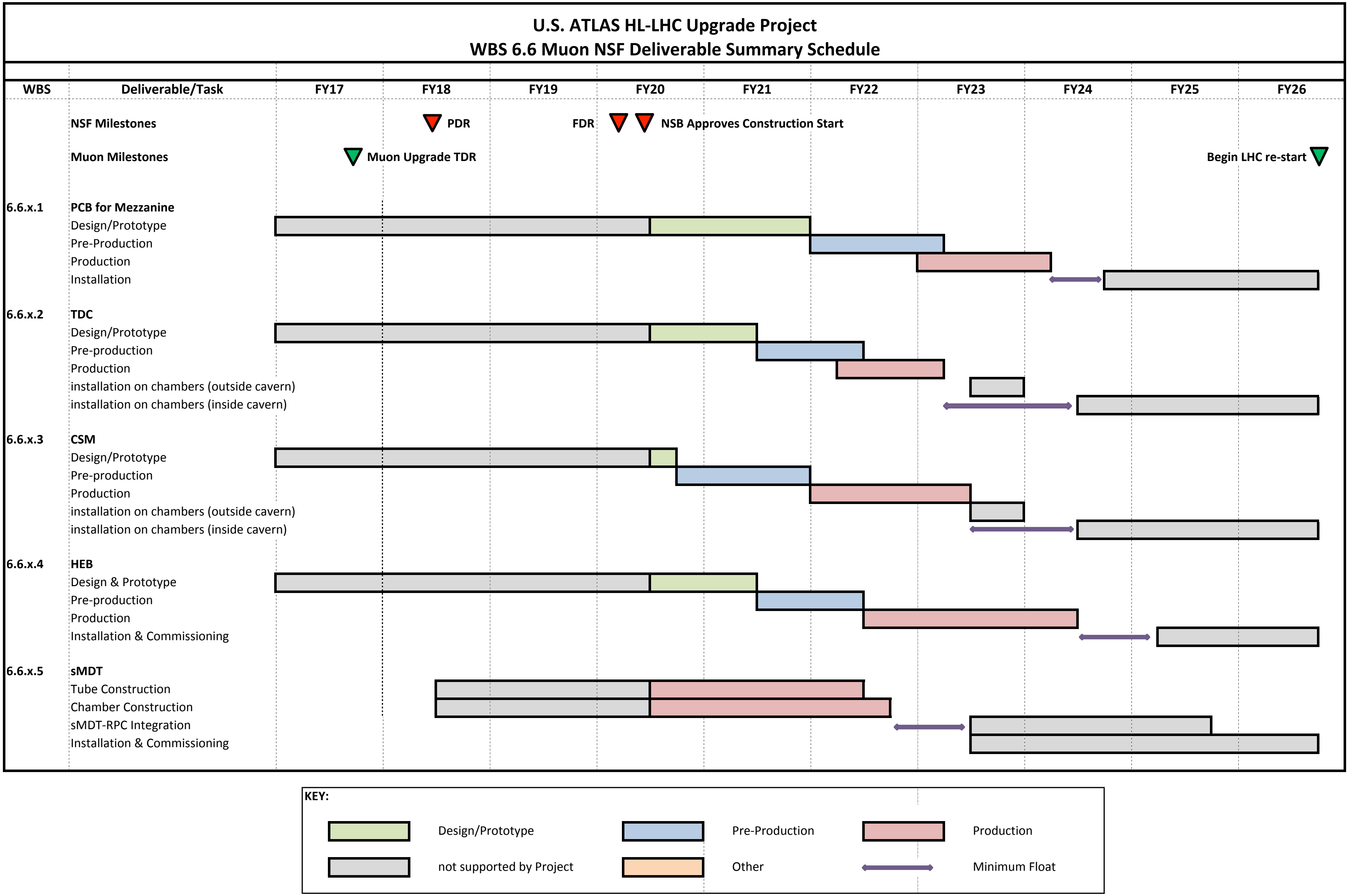
Labor by Phase

6.6 Muon NSF Total FTEs by Phase						
Deliverable/Item/Phase	**FY20**	**FY21**	**FY22**	**FY23**	**FY24**	**Grand Total**
6.6.1 Muon_Arizona	**1.02**	**1.95**	**1.60**	**2.14**	**1.47**	**8.18**
6.6.1.1 PCB for Mezzanine	**1.02**	**1.95**	**1.60**	**2.14**	**1.47**	**8.18**
Design	1.02	1.95	0.93	-	-	3.90
Prototype	-	-	0.67	0.67	-	1.35
Production	-	-	-	1.47	1.47	2.94
6.6.3 Muon_Michigan	**5.50**	**10.75**	**9.65**	**3.50**	**-**	**29.40**
6.6.3.2 TDC	**1.50**	**2.75**	**2.75**	**1.50**	**-**	**8.50**
Design/Prototype	1.50	1.50	-	-	-	3.00
Pre-Production	-	1.25	1.25	-	-	2.50
Production	-	-	1.50	1.50	-	3.00
6.6.3.3 CSM	**2.00**	**4.00**	**3.90**	**2.00**	**-**	**11.90**
Design/Prototype	0.80	-	-	-	-	0.80
Pre-Production	1.20	4.00	-	-	-	5.20
Production	-	-	3.90	2.00	-	5.90
6.6.3.5 sMDT	**2.00**	**4.00**	**3.00**	**-**	**-**	**9.00**
Tooling Construction	-	-	-	-	-	-
Tube Construction	-	-	-	-	-	-
Chamber Construction	2.00	4.00	3.00	-	-	9.00
6.6.4 Muon_Illinois	**1.00**	**2.00**	**2.00**	**2.00**	**1.00**	**8.00**
6.6.4.4 HEB	**1.00**	**2.00**	**2.00**	**2.00**	**1.00**	**8.00**
Design/Prototype	1.00	1.00	-	-	-	2.00
Pre-Production	-	1.00	1.00	-	-	2.00
Production	-	-	1.00	2.00	1.00	4.00
6.6.5 Muon_MSU	**1.00**	**2.00**	**1.75**	**-**	**-**	**4.75**
6.6.5.5 sMDT	**1.00**	**2.00**	**1.75**	**-**	**-**	**4.75**
Tooling Construction	-	-	-	-	-	-
Tube Construction	1.00	2.00	1.75	-	-	4.75
Chamber Construction	-	-	-	-	-	-
NSF Grand Total	**8.52**	**16.70**	**15.00**	**7.64**	**2.47**	**50.33**

Distribution at Institutions (L3)

6.6 Muon NSF Level 3 Cost (AYk$)						
	FY20	**FY21**	**FY22**	**FY23**	**FY24**	**Grand Total**
NSF						
6.6.1 Muon_Arizona	138	261	302	1,253	92	2,046
6.6.3 Muon_Michigan	708	2,724	1,780	280	0	5,491
6.6.4 Muon_Illinois	174	347	348	1,126	185	2,180
6.6.5 Muon_MSU	270	537	439	0	0	1,246
NSF Total	**1,291**	**3,868**	**2,869**	**2,659**	**277**	**10,964**

Schedule built from scoping document and consultation with ATLAS management (particularly Muon Project Leader Christoph Amelung)



Risks

Low risk due to experience of personnel and similarity of deliverables to previous projects. More detail in the BoE's. These are the largest risks.

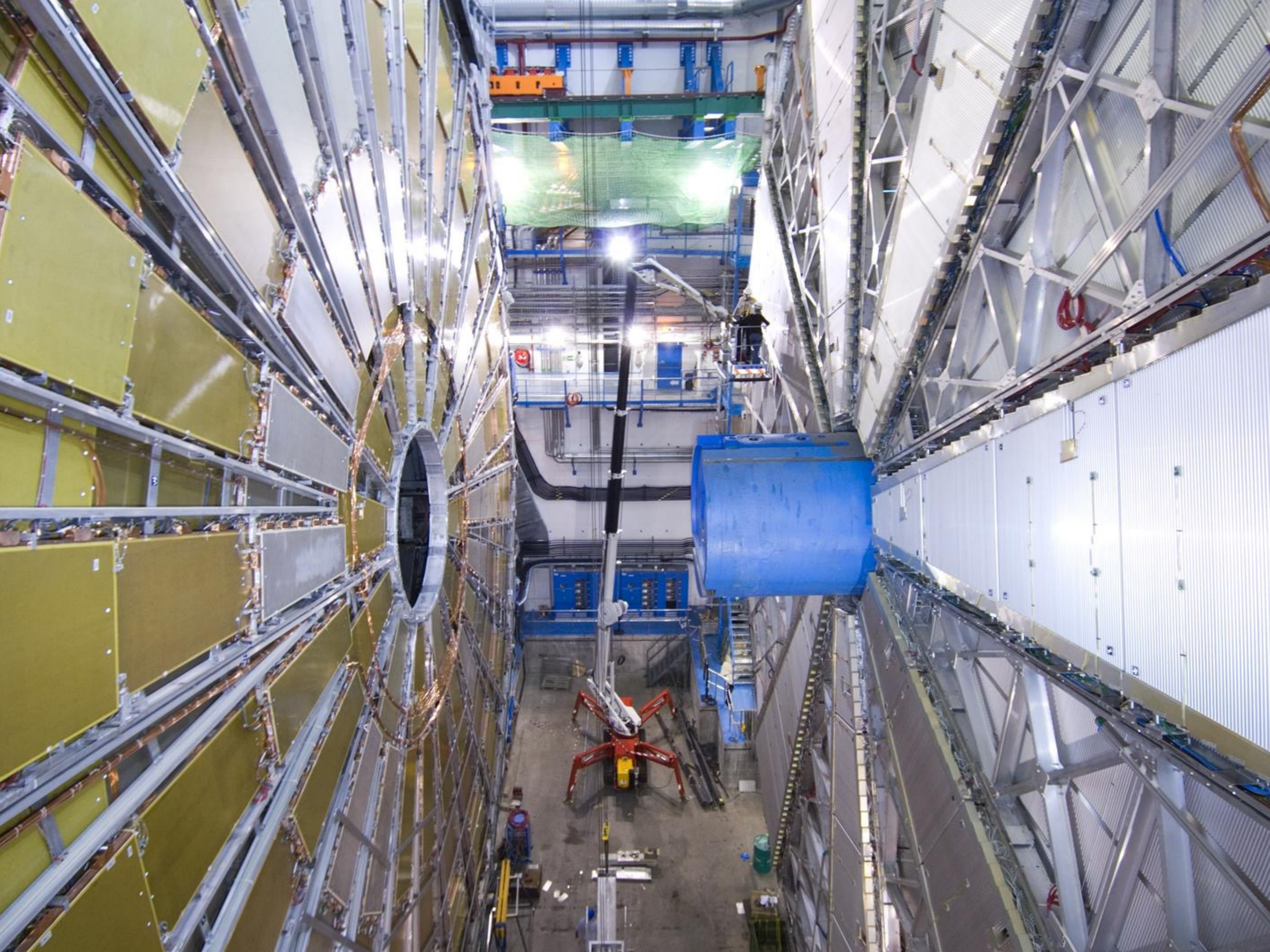
Schedule Risk:

- **Probability:** Low
- **Potential Problem:** Some mezzanine cards in the detector will be unreachable and therefore cannot be replaced.
- **Mitigation:** Jr EE hired to handle CSM firmware modifications such that these chambers can still be read out with the new front-end system.

Schedule Risk:

- **Probability:** Low
- **Potential Problem:** Current motherboard and cables that connect the mezzanine and the CSM cannot handle the data rates required for the new CSM and new Mezzanine. If the cables need to be replaced it will require more work on-detector.
- **Mitigation:** Tests have been performed on the current motherboard/cables to demonstrate they can handle required data rates for the maximum cable lengths needed for the new designs. We are only considering system designs that can utilize these cables.

Please see Risk Registry for more



Contingency and Opportunity

- 35% Budget Contingency for low-risk system
  - Material Contingency Rule 4:
    - "25-40% contingency on: items that can be readily estimated from a reasonably detailed but not completed design; items adapted from existing designs but with minor modifications, produced within the previous two years, with documented costs. A recent vendor survey based on a preliminary design belongs here."
    - Some quotes are also integrated into estimates, but this is a conservative rule to apply.

  - Labor Contingency Rule 3:
    - "25-40% contingency for a task that is conventional, well defined and tends to be repeatable with good confidence but can expect small fluctuations; .for example, testing of production electronics components (most boards take the same unit time, a few take longer); for example, fabrication of multiple similar components but which are not an assembly-line process; for example, design labor for conventional items which offer little to no technical risk."
    - We did assume 3% inflation on top of actual 2016 salaries.

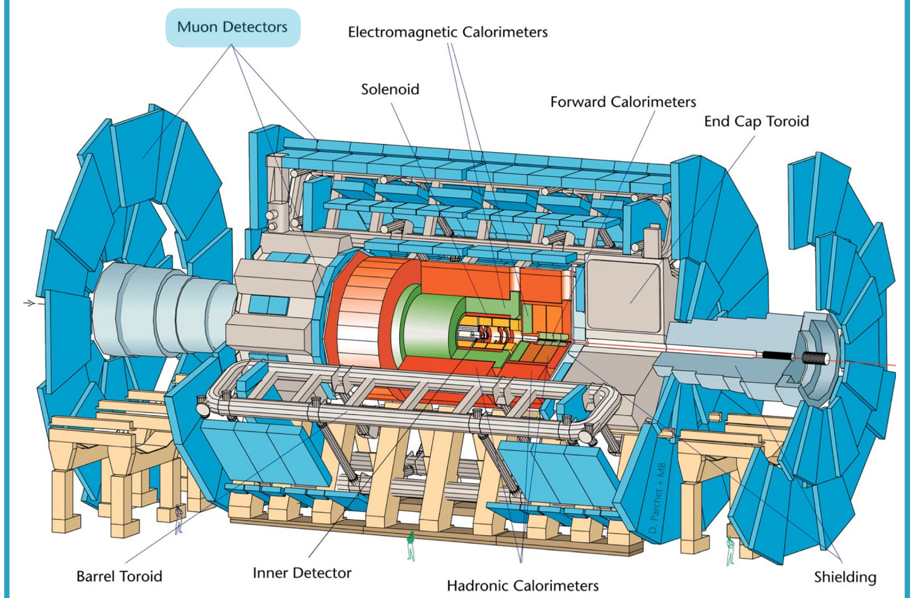
- Scope Contingency
  - TDC (6.6.3.2)
    - US task would reduce to design only. MPI (Germany) and USTC (China) have been identified as likely institutes to take over construction.
    - Decision probably would need to be made FY20/FY21 to allow enough time for US and ATLAS management to find another institution.
    - <u>Save $1.2M</u>

- Scope Opportunity
  - There is no scope opportunity. We are leading the most important deliverables for the muon spectrometer system. Any other deliverables outside this scope take us away from our expertise and do not fit within the theme of our scope.

Closing Remarks

- NSF taking the most impactful components of the HL-LHC upgrade for Muons.
- All deliverables led by institutes with previous experience and strong existing infrastructure.
- We are fairly invariant to ATLAS decisions. Projects are high priority and exist in all ATLAS scoping scenarios.
- The TDC faces some international competition. The ASIC-based TDC could be an option not selected by ATLAS.
- Institutes working on CSM, HEB, and TDC are already performing R&D towards developing a demonstrator system for the TDR (Due June 30th, 2017).

WBS	Deliverable	US Institutes
6.6.x.1	**PCB for Mezzanine**	University of Arizona ***6.6.1.1***
6.6.x.2	**Time-to-Digital Converter (TDC)**	University of Michigan ***6.6.3.2***
6.6.x.3	**Chamber Service Module (CSM)**	University of Michigan ***6.6.3.3***
6.6.x.4	**Hit Extraction Board (HEB)**	University of Illinois Urbana-Champaign ***6.6.4.4***
6.6.x.5	**sMDT**	Michigan State University (tubes) ***6.6.5.5*** University of Michigan (chambers) ***6.6.3.5***



6.06 Muon NSF Total Cost (AYk$)						
	FY20	FY21	FY22	FY23	FY24	Grand Total
NSF						
Labor	923	1,874	1,632	764	267	5,460
M&S	339	1,949	1,192	1,868	2	5,350
Travel	28	45	45	27	8	154
NSF Total	**1,291**	**3,868**	**2,869**	**2,659**	**277**	**10,964**